Review of Carbon TerraVault (CTV) Responses to EPA's Questions about Construction and Plugging Procedures for Injection Well 355-7R at the CTV-Elk Hills Monterey Formation A1-A2 Class VI Project

In February 2022, EPA provided questions to CTV (*blue, italic text*) about the construction and plugging of the 355-7R injection well to inject CO_2 into the Monterey Formation A1-A2 Sands, submitted as part of CTV's Class VI permit application (dated August 30, 2021 and December 2, 2021) for the proposed CTV-Elk Hills Class VI geologic sequestration (GS) project. CTV provided updated operating procedures for the two wells to EPA on May 16, 2022. EPA's evaluation of how the update addresses its questions is presented in red below. Requests for revisions and additional information are presented in ***red, bold, and italic*** below. Previous responses that require no further information are not included in this enclosure.

Injection Well Construction

Narrative A2 and Attachment G2 describe the construction design for Well 355-7R. Well 355–7R is an existing Class II pressure maintenance well, approved by CalGEM (California Geologic Energy Management Division) to inject up to 50 mmscf (million standard cubic feet) of CO_2 per day. The applicant states that Well 355–7R was constructed using CO_2-resistant materials and can meet operating conditions for the injection of CO_2. Well 355-7R was drilled in 1973; Narrative A2 contains construction details regarding Well 355-7R.

Table 5 of the Narrative A2, matches the casing specifications listed in Attachment G2 for Well 355-7R (see below). Attachment G2 also includes tubing and packer specifications for Well 355-7R, which are excerpted below. The tubing and packer specifications in Attachment G2 mostly correspond to Table 7 of the Narrative A2, however there appear to be typos regarding: tubing outside diameter and weight (in the Narrative A2) and regarding packer tensile rating (in Attachment G2).

Injection Well 355-7R Construction Details (from Attachment G2)

Casing Specifications

Name	Depth Interval (feet)	Outside Diameter (inches)	Inside Diameter (inches)	Weight (lb/ft)	Grade (API)	Design Coupling (Short or Long Threaded)	Thermal Conductivity @ 77°F (BTU/ft hr, °F)	Burst Strength (psi)	Collapse Strength (psi)
Conductor	14 - 60	20.000	19.5	52	H-40	Short	31	875	90
Surface	14 - 500	13.375	12.715	48	H-40	Short	31	1,727	740
Intermediate	14 - 520 520 - 3,393	9.625	8.835	40	N-80 K-55	Long	31	5,750 3,950	3,090 2,570
Long-string	14 – 43 43 – 4,089 4,089 – 5,796 5,796 – 8,363 8,363 – 9,500	7.000	6.184 6.366 6.276 6.276 6.184	29 23 26 26 29	N-80 K-55 K-55 N-80 N-80	Long	31	8,160 4,360 4,980 7,240 8,160	7,020 3,270 4,320 5,410 7,020

Tubing Specifications

Name	Depth Interval (feet)	Outside Diameter (inches)	Inside Diameter (inches)	Weight (lb/ft)	Grade (API)	Design Coupling (Short or Long Thread)	Burst strength (psi)	Collapse strength (psi)

Injection tubing	8,398	4.500	3.920	13.5	L-80	Long	9,020	8,540

Packer Specifications

Packer Type and Material	Packer Setting Depth (feet bgs)	Length (inches)	Nominal Casing Weight (lbs/ft)	Packer Main Body Outer Diameter (inches)	Packer Inner Diameter (inches)
Baker-Hornet, Ni plated	8,403	95.4	23-29	6.000	2.920

Tensile Rating (lbs)	Burst Rating (psi)	Collapse Rating (psi)	Max. Casing Inner Diameter (inches)	Min. Casing Inner Diameter (inches)
10,0000	8,000	8,000	6.466	6.184

CTV states that all the well materials and the stainless-steel wellhead are designed to be compatible with the CO_2 injectate and expected subsurface temperature and pressure regimes. The surface and downhole pressure gauge and logging tool specifications detailed in Tables 8-14 of the quality assurance surveillance plan (QASP) are consistent with the well construction equipment and surface and subsurface temperature and pressure conditions. The Applicant notes that the Class G Portland cement used to complete well 355-7R, with cement to surface for each stage, has been used extensively in enhanced oil recovery injectors. Each casing string, except for the surface conductor and long string (injection string), had cement returns to surface according to Narrative A2. A CBL indicated that the top of cement in the injection string annulus is above 5,200 ft, which is above the Reef Ridge Shale upper confining layer, reported as 6,929 ft-7,962 ft true vertical depth (TVD), per Table 1 of the Narrative A2.

The cement integrity is supported by information from existing wells and a CBL in Well 355-7R. California Resources Corporation (CRC) has conducted standard annulus pressure tests (SAPTs) historically to ensure continued internal mechanical integrity of the well. No SAPT results were provided in the permit application materials, however. These tests will also be conducted prior to injection and every five years thereafter and are discussed further in the *Pre-Operational Testing* section of this evaluation.

Figure 1 of Attachment G2 is illegible, so information such as geologic formation tops (for the injection and confining zones and the Base of the USDW), perforation depths, and casing depths, cannot be evaluated. The applicant will need to resubmit an updated, resolvable casing diagram for Well 355-7R that demonstrates proper construction, including that the Base of the lowermost USDW is covered by the surface casing in accordance with 40 CFR 146.86(b)(2). According to the tables on Page G2, the surface casing is set to a depth of 500 feet; however, the average depth of the Tulare Formation (Upper and Lower) within the AoR is 600-2,500 ft (as reported on pg. 31 of the Narrative). EPA is requesting clarification of the depth of the Upper Tulare Formation (the lowermost USDW) in its questions on the geologic narrative, and CTV's response to this question will help confirm whether the surface casing is sufficiently deep to protect the lowermost USDW in accordance with 40 CFR 146.86(b)(2). (Based on the aquifer exemption record of decision for the Elk Hills Oil Field, the Upper Tulare is shallower than 400 feet.)

The applicant did not provide a pre-operational testing plan to test the compatibility of the injectate with well construction materials.

The Emergency and Remedial Response Plan, described in Attachment F, provides a description of the events that may necessitate gradual or immediate shutdown of the well depending on the severity of

the event. However, the applicant did not provide discussion regarding safety valves and automated shut-off devices in Attachment G2.

The permit application Narrative (on pg. 2) notes that the "…continuously subsiding [San Joaquin] basin is a sediment filled depression that lies between the Sierra Nevada and Coast Ranges and is 450 miles long by 35 miles wide." The effects of subsidence on the mechanical integrity of injection wells has been cited as a concern in other California oil fields, and some operators have developed mitigation measures to relieve stress on the surface casing (e.g., via wellhead design that allows differential movement between the casings).

Questions/Requests for the applicant:

- *Is Well 355-7R equipped with automatic shutoff systems connected to the real-time surface monitoring equipment and alarms, as required at 146.88(e)(2)? If so, please describe these systems in Attachment G2 and how the safety valves and shut-off devices will be linked to the continuous injection and annulus monitoring system. If not, please update Attachment G2 to include these required components. Under "Alarms and Shut-off Devices" on page 5, the applicant states that real time monitoring and automated shut off controls will be added to the system. CTV is required to provide information for EPA to review before installing the equipment; these should be included on final as-built schematics of the well. CTV states that they do not plan to install down hole shut off systems due to the lack of risk factors (e.g., high temperatures and pressures or corrosive materials). Additional clarification on why these risk factors are considered low is required.*
- *Figure 1 of Attachment G2 is illegible. Please submit an updated, resolvable diagram for Well 355-7R that includes the following information:*
  - *All relevant formations (e.g., the injection and confining zones and the base of the USDW); These details were added to a wellbore diagram of the injection well in the confidential Appendix 1 - Monitoring Well Schematics and Plugging Details.*
  - *Surface casing that extends through the Base of the USDW, per 40 CFR 146.86(b)(2); Although the Construction, Operating and Plugging document (COP) states that surface casing is set and cemented within the USDW, according to the well schematic, the surface casing only extends to 500' which is above the bottom of the USDW at 840'. 40 CFR 146.86(b)(2) requires the surface casing must extend through the base of the lowermost USDW.*
- *For completeness, please include the description of testing of the deep monitoring wells (i.e., as described in Attachment G) in Attachment G2. The applicant states that these details will be incorporated into the pre-operational testing document, but did not include it. i*
- *Please explain how the injection well's design will mitigate potential shallow compression related to land subsidence while still complying with the requirement to cement to the surface. The applicant describes in the Casing section on pages 2 and 3 that there has been no historical occurrence of subsidence in the area. In addition, the COP states that well construction mimics other wells used in the area for injection with no operational issues related to structural strength. No evidence of this was provided, however.*

- *Please provide the most recent SAPT reports for the well. The most recent SAPT results from October 6, 2020, are provided on page 9 of the document, which shows the well maintaining pressure within the well annulus, demonstrating mechanical integrity. However, the SAPT was run for 30-40 minutes, and not the minimum of 60 minutes as described in the pre-injection testing in Appendix G2 submitted with the initial application materials. Because CTV will conduct an additional SAPT prior to injection, this response is acceptable at this point.*

Follow-up Requests for the Applicant

- ***Please clarify why the risk factors (temperature, pressure and corrosivity) are considered to be low and include further justification as to why the downhole shutoff system is not necessary.***
- ***Please confirm the base of the lowermost USDW. Please note the definition of USDW (40 CFR 146.3) below.***

  (USDW) means an aquifer or its portion:
  (1)(i) Which supplies any public water system; or (ii) Which contains a sufficient quantity of ground water to supply a public water system; and
  (A) Currently supplies drinking water for human consumption; or
  (B) Contains fewer than 10,000 mg/l total dissolved solids; and
  (2) Which is not an exempted aquifer.
- ***Please provide data or sources as evidence that lead to the determination that no subsidence has occurred in the area.***
- ***EPA requests that, for clarity, the conductor casing grade (which was reported as H-40 in the initial application) be included on Table 1. If this information was incorrect, please explain how the conductor casing is suitable for CO_2 injection.***
- ***Because the tubing grade was changed from 13CR-95 to L-80 CRA, please ensure that the coupons used in the corrosion monitoring section of the Testing and Monitoring Plan are revised accordingly.***
- ***Please update Attachment G2 to include the pre-operation testing plan for the deep monitoring wells.***
- ***Please provide a pre-operational testing plan to test the compatibility of the injectate with well construction materials.***

Injection Well Pre-Operational Testing

The proposed pre-operational formation and well testing program for Well 355-7R required at 40 CFR 146.82(a)(8) and 146.87 is described in Narrative A2 and in Attachment G2. Attachment G2 identifies several tests that CTV indicates have been performed and were provided. These include deviation checks, a cement bond log, and open-hole well logs. CTV notes that mechanical integrity tests, including a temperature log and SAPT, were also acquired after the drilling of 355-7R; however, these were not provided. Attachment G2 also indicates that a SAPT, Temperature Log, and Radioactive Tracer Survey will be conducted prior to injection operations.

In the Testing and Monitoring Plan, CTV says that it "does not currently plan to complete pressure fall off testing" (pg. 10), given the extent of available information about the Monterey Formation A1-A2

Sands. However, a pressure fall off test must be performed prior to injection. See the testing and monitoring evaluation for additional discussion.

Cement bond logs and SAPTs of the injection wells are listed in Table 1 of the QASP (Summary of testing and monitoring). It appears that a SAPT was previously run and will be run prior to injection, but Attachment G does not indicate that a CBL will be run. Clarification on the well testing to be performed is needed.

Questions/Requests for the applicant:

- *The CBL provided with the Logging and Testing plan does not cover the entire injection and confining zones. Please provide a CBL that covers the entire injection and confining zones and explain the varying amplitude and seismogram signal throughout both zones. The applicant states that a full well CBL will be completed during pre-operational testing and tubing removal. The pre-operational testing plan submitted with the initial application in Appendix G2 includes a micro-seismogram log for cement evaluation, but not a CBL. If the purpose of this testing is to evaluate cement condition, the response is acceptable, although CTV should clarify the tests to be performed in their updated pre-operational testing plan. EPA will need to review and approve the results of the CBL prior to authorizing injection.*

Follow-up Requests for the Applicant

- ***Please provide an updated pre-operational testing plan that describes the tests identified in CTV's responses to questions in this document. For example, the plan should include: an SAPT of an appropriate test duration and MITs on monitoring wells 342-7R-RD1 and 327-7R-RD1.***

Objectives for Pre-Operational Testing

Based on the site characterization, AoR delineation modeling, and testing and monitoring evaluations, EPA has identified the following objectives for the planned pre-operational testing to address data gaps identified during the review. This information is summarized below (along with the planned tests that will address each data need) for reference and to clarify EPA's expectations for the updated materials that CTV must submit pursuant to 40 CFR 146.82(c).

Regional Geology and Geologic Structure

- Confirm hydraulic separation of the Monterey A1-A2 reservoir and the Monterey Formation A3-A11 reservoir (anticipated testing method: downhole pressure measurement via gauges).
- Perform pressure build-up testing as part of the Pre-Operational Testing plan (anticipated testing method: pressure build-up test).
- Confirm the fracture pressure of the injection and confining zones (anticipated testing method: step-rate test in each zone using a representative fluid).

Geochemistry/Geochemical Data

- Establish baseline geochemistry for the Monterey Formation, as well as the Tulare and Etchegoin Formations for all analytes to be monitored during injection operations, per the Testing and Monitoring Plan (anticipated testing methods: various geochemical analyses).

Seismic History and Seismic Risk

- Establish baseline seismicity (anticipated testing method: existing seismic network/historic seismicity database).

Facies Changes in the Injection or Confining Zones

- Determine if there are any heterogeneities within the Monterey A1-A2 that could affect its suitability for injection, including facies changes that could facilitate preferential flow (anticipated testing methods: pressure build-up test; also, core, log, seismic analysis have been performed).

CO_2 Stream Compatibility with Subsurface Fluids and Minerals

- Confirm the composition and water content of the CO_2 injectate as part of baseline sampling and verify that it will not react with the formation matrix (anticipated testing methods: various geochemical analyses).
- Confirm that the properties of the CO_2 stream are consistent with the AoR delineation model inputs (anticipated testing methods: various geochemical analyses).
- Confirm that the analytes for injectate and ground water quality monitoring are appropriate based on the results of geochemical modeling evaluation (anticipated testing methods: various geochemical analyses).

Confining Zone Integrity

- Test for changes in capillary entry pressure of the Reef Ridge Shale due to reaction of the shale with the injectate (anticipated testing method: mercury injection capillary pressure).

Injection Well Construction

- Following the pre-construction measurement of the composition, properties, and corrosiveness of the injectate, review the well construction materials and cement in the context of the results of these tests (anticipated testing methods: various geochemical analyses).

Well Stimulation

The application materials do not include a stimulation plan. 40 CFR §146.88(a) requires that all stimulation programs be approved by the EPA Director as part of the permit application and incorporated into the permit. If the initial permit does not include a stimulation program and the operator identifies a need for well stimulation later in the life of the project, a major permit modification would be necessary. EPA suggests that CTV consider preparing and including a proposed well stimulation program in the permit application. A generic stimulation program may be used for the pre-construction phase of the project.

Questions/Requests for the applicant:

- *To avoid the need for a permit modification if stimulation were to become necessary in the future, EPA requests that CTV prepare a draft stimulation plan. EPA can provide some additional guidance about the content of the plan, but anticipates that the plan should describe:*
    - *The stimulation fluids to be used, including any additives (e.g., corrosion inhibitors, clay inhibitors, biocides, complexing agents, or surfactants) or diverting agents; and*
    - *Step-by-step procedures that would be employed during stimulation.*

The updated Attachment I (Stimulation Plan) states that stimulation is not anticipated and that a plan will be submitted for approval should stimulation be required; it contains no general description of stimulation procedures. EPA has communicated with CTV that a stimulation plan submitted after the permit is issued will necessitate a modification to the permit. CTV has chosen to not include a stimulation plan at this point.

Monitoring Well Pre-Operational Testing

The pre-operational formation well testing program for monitoring wells 342-7R-RD1 and 327-7R-RD1 is described in Attachment G. These wells have been drilled and completed, and data from deviation checks and open-hole well logs were acquired. Demonstration of mechanical integrity will be conducted via mechanical integrity logs and tests prior to injection operations. A SAPT will also be conducted for each monitoring well. However, the type of MIT methods planned for mechanical integrity demonstration prior to injection was not discussed.

Questions/Requests for the applicant:

- *What specific MITs are planned for monitoring wells 342-7R-RD1 and 327-7R-RD1? The applicant says they will address this within their pre-operational testing plan. MITs referenced in the original Attachment G include annulus pressure tests only. For existing wells that are proposed to be converted, an external MIT will be required.*
- *Please include information about MITs on the deep monitoring wells in Attachment G2 for completeness. The applicant says they will address within the pre-operational testing plan. MITs referenced in the original Attachment G include procedures for conducting annulus pressure tests on the deep monitoring wells.*

Follow-up Requests for the Applicant

- ***Please include an external MIT in the pre-operational testing plan for wells that are proposed to be converted to monitoring wells.***